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Atmospheric Chemistry and Physics Discussions

Interactive comment on "Biological residues define the ice nucleation properties of soil dust" *by* F. Conen et al.

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We thank Paul DeMott for his constructive comments that help us clarify our views on this complex and diverse topic.

1. Introduction

Page 16586, lines 22-23: As we understand now, the number of particles larger than 0.5 microns correlates well with number of IN because particles that size are more likely to be primary particles, such as soil dust or bacteria, than secondary particles of other origin without IN properties.

Page 16587, line 5: The work of G. Vali and R. C. Schnell is a great inspiration to us. We regret it has not been made clear that the relation between soil organic matter

and ice nucleation was first discovered by G. Vali in 1968. The finding that numbers of IN on decayed leaf litters are different between major climatic zones (Schnell and Vali, 1973) suggests why there may not be a simple global relation between IN and soil organic carbon (as we indicated on page 16590, lines 5-14). The paper by Schnell and Vali (1973) guides us to the next study, where we will try to establish such relations for different climatic zones.

2. Materials and methods

Page 16587, line 25: Wet sieving is the standard technique to separate different particle size fractions in soil. The dried soil is immersed in water on a sieve of a given mesh and water is rinsed through, taking with it the particles that are smaller than the mesh size. The procedure releases some dissolved organic carbon that may be redistributed among particle size fractions. In a study on over 100 soils of different origin, Zimmermann et al. (2007) measured an average loss in form of dissolved organic carbon of 1.5 % of the total organic carbon in soil by wet sieving. Thus, the vast majority of the organic carbon distribution of the undisturbed sample remains intact.

Page 16588, line 5: Thank you for the clarification and the reference.

3. Results and discussion

Page 16589, line 9: Organic carbon content was determined by dry combustion using an elemental analyzer (Flash-EA 1112, Thermo Electron, Milano, Italy).

Page 16589, lines 15-16: From our perspective, "biological origin" or "biological residues" both mean the same thing - that the materials are from a once-living organism.

Of course, the uncertainty in our back of the envelope calculation could be an order of magnitude. Yet, the soil samples had been air dried before sieving and analysis. Air drying reduces the number of intact bacteria. Furthermore, one of the main IN active species, Pseudomonas syringae, is almost never detectable in soils, even in fresh soils.

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This plant pathogen has no extended soil phase (Goodnow et al., 1990, and references therein). Therefore, we think the estimates of intact IN active bacteria in our samples are optimistically high ones.

Page 16590, lines 12-19: The main difference to the study by Schnell and Vali (1973) on leaf litters is that we analysed soil particles of a size small enough to be potentially transported to cloud altitude. Material analysed in the earlier study (leaf litter) was not expected to become airborne, but to release nuclei into the atmosphere. A second difference is that the biological residues associated with decayed leaf litter is generally much younger than residues associated with mineral particles (Conen et al., 2008).

Page 16591, lines 7-9: We fully agree that the methods we used are not able to distinguish between a freezing event caused by a purely biological particle from a freezing event caused by a biological residue associated with a mineral particle. However, as mentioned on page 16587, lines 18-20: "Even in soils with a small organic matter content (1–2 % organic carbon (w/w)) up to 50 % of the particle surface area can be covered with such residues (Kahle et al., 2002)." This does not mean there are no purely biological particles in a soil sample. But, the vast majority of organic surface in a soil sample comes as coating on mineral particles. The surface of purely biological particles is likely to be a very small proportion of the total soil particle surface. Assume a soil sample with 1 % of organic carbon (w/w) where mineral particles do not associate with biological residues, and biological residues consist to 50 % of carbon and have half the specific density of the minerals. In such a soil sample, only 4 % of the total surface would be provided by biological material, whereas in a natural sample, where biological residues associate with mineral particles, this proportion is an order of magnitude larger. If there is no preference of IN proteins to stay away from mineral particles, and this is unlikely because proteins adhere very strongly to mineral surfaces, it seems safe to assume that a majority of the nucleation events observed in our study were caused by biological residues associated with mineral particles rather than by purely biological particles.

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3. Conclusions

It is a nice suggestion to put the results in context with expected atmospheric concentrations. PM10 data from the High Altitude Research Station Jungfraujoch (7° 59' E, 46° 33' N; 3450 m above sea level) in the Swiss Alps show for the past 12 months a median daily PM10 value of 2.0 microgram m^{-3}. On 1 of 10 days, PM10 concentrations exceeded 7.5 microgram m^{-3}, in 1 of 20 days, they exceeded 10.6 microgram m^{-3} (http://www.bafu.admin.ch/luft/luftbelastung/). The large values are usually associated with Saharan dust events. We have not yet tested Saharan dust, but expect it to be low in organic carbon and, as it comes from a warm climatic zone, to carry a small number of IN per unit organic carbon. Hence, we would expect only a few tens of IN m^{-3} active at -12 ^{o}C during such an event. Air masses with back trajectories north of the Alps sometimes carry more than 5 microgram PM10 m^{-3}. One microgram of such material would need to contain about 200 IN to have an effect on cloud development. Such a number is between the numbers we found for soil C and D. A combination of soil IN analyses in different dust source regions and back trajectories may shed more light on whether and when biological particles may affect cloud processes. We are currently planning such a study.

References:

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Goodnow, R. A., Harrison, M. D., Morris, J. D., Sweeting, K. B., Laduka, R. J. (1990) Fate of ice nucleation-active Pseudomonas syringae strains in alpine soils and waters and in synthetic snow samples. Appl. Environ. Microbiol. 56, 2223-2227.

Zimmermann, M., Leifeld, J., Schmidt, M.W.I., Smith, P., Fuhrer, J. (2007) Measured soil organic matter fractions can be related to pools in the RothC model. European Journal of Soil Science 58: 658-667.)

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